Mayer (A. M.)

[From the American Journal of Science and Arts, Vol. IV, Nov., 1872.]

ON A METHOD OF DETECTING THE PHASES OF VIBRATION IN THE AIR SURROUNDING A SOUNDING BODY;

AND THEREBY MEASURING DIRECTLY IN THE VIBRATING AIR THE LENGTH OF ITS WAVE AND EXPLORING THE FORM OF ITS WAVE-SURFACE.

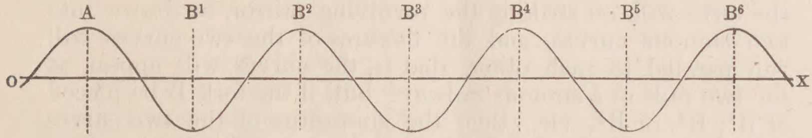
By ALFRED M. MAYER, Ph.D.,
Professor of Physics in the Stevens Institute of Technology, Hoboken, N. J.

[From the American Journal of Science and Arts, Vol. IV, Nov., 1872.]

ON A METHOD OF DETECTING THE PHASES OF VIBRATION IN THE AIR SURROUNDING A SOUNDING BODY; AND THEREBY MEASURING DIRECTLY IN THE VIBRATING AIR THE LENGTH OF ITS WAVES AND EXPLORING THE FORM OF ITS WAVE-SURFACE.

By ALFRED M. MAYER, Ph.D.,
Professor of Physics in the Stevens Institute of Technology, Hoboken, N. J.

The curve A, B^2, B^4, etc., is the well known symbolic representation of the dynamic condition of the air, at a given instant, when traversed by simple sonorous vibrations. Those portions of the curve above the axis OX represent the length and manner



of the aerial condensations, while those flexures below the axis represent the rarefactions; therefore similar points of the flexures above the axis, or similar points in the flexures below the axis, represent like phases of vibratory motion. Imagine these conditions of the air produced by a body vibrating at A; then the distance A to B^1, B^1 to B^2, etc., will equal a half wave-length, while from A to B^2, B^2 to B^4, etc., will represent a whole wave-length, corresponding to the note given by A. If another sonorous body B, giving exactly the same note as A, be placed anywhere on OX, it will have vibrations communicated to it from the vibrating air which touches it, and it will vibrate exactly with the air, almost as though its substance was of the air itself. Now imagine this body B placed at B^2, or at B^4, or B^6, etc., then its phases of vibration will be exactly similar to those of A; but when placed at B^1, B^3 or B^5, etc., its phases of vibration will be opposed to those of A. That is, at dis-

tances from A, equal to any number of whole wave-lengths the body B will, at the same moment of time, swing with A, but at distances from A equal to any number of half wave-lengths the direction of its swings, at any given instant, will be opposed to A; while at intermediate positions, on the line OX, the oscillations of B will be lagging somewhat behind or be slightly in advance of the phase of A's vibration.

After this it is evident that if, by any means, we can *see at the same time* the vibrations of A and of B, we will (if the received conception of the nature of a vibration's propagation is correct) see their motions just as has been described above, and will therefore be able to measure, *directly in the air*, a wave-length and to determine any wave surface enclosing a vibrating body. I have devised several processes. I will, however, here describe only two; the first, though impracticable, I speak of to render clear the general method of all; the second I give on account of its simplicity, ease of execution, and the superior accuracy of its numerical results.

Take two tuning forks giving the same note and having mirrors attached to their similar prongs; place one at A, the other anywhere on the line OX. Reflect a pencil of light from each mirror of the forks to a revolving mirror, whose axis of rotation is in a plane parallel to the planes of vibration of the forks. If the fork B, which vibrates sympathetically, be placed at B^2, B^4, B^6, etc, then the two pencils reflected from the forks will, on striking the revolving mirror, be drawn into two sinuous curves, and the flexures of the two curves will run parallel to each other, that is, the curves will appear as the two rails of a sinuous railway; but, if the fork B be placed at B^1, B^3, or B^5, etc., then the sinuosities of the two curves will no longer be parallel but will be opposed; that is, where a flexure of one of the curves is concave on the left, the opposite flexure of the other curve will have its concavity on the right. If the fork B be placed at intermediate positions, in reference to those above stated, we will have neither concordance nor opposition of the flexures, but intermediate relations depending on the fraction of half wave-lengths at which the sympathetic fork is placed on the line OX.

It is now readily seen that if we should place the fork B at two successive points, as B^2 and B^4, on the line OX, so that exact concordance of flexures of the curves should be seen at each of these points, then evidently we have placed the fork at two positions removed from each other by a wave-length, for at these points the air had at the same instant the same phase of vibration. Thus we have measured a wave-length. Furthermore, if by any means we could move the fork B around A so that during this motion it always preserved, in reference to

A, the same relation of vibratory phase, we would have determined the form of the wave-surface produced by the propagation of A's vibrations.

The above is an exposition of the thoughts that have occupied my mind for several months, and they ultimately led to the following method, by which all I have narrated can be accomplished without any difficulty; thanks to the inventive genius of Mr. König, to whose skillful aid so many physicists are continually indebted.

The membranes of Mr. König's manometric capsules furnish us with surfaces which vibrate in perfect accordance with the air which touches them, and we can lead the impulses of these membranes through gum tubes to gas jets placed at any desired point, where the vibrations of their flames can be compared. Thus they are far superior to the tuning forks, which require the relations of delicate adjustments to be maintained during each change of position, and therefore forks could only with difficulty be made to serve in the measure of a wave-length, and could not at all be employed to trace out a wave-surface on account of the impossibility of a continuous comparison of their vibrations, which latter condition the manometric flames admirably fulfill.

The Experiments.

Let us now proceed to experiment. I placed on the acoustic bellows an open UT_3 organ pipe, and from its ventral manometric capsule I led a tube to a gas jet placed in front of a cubical revolving mirror. I took an UT_3 Helmholtz resonator and adapted to its beak a gum tube, with an interior diameter of 1 centimeter and a length of over 4 meters. This tube led to a firmly supported manometric capsule whose flame was placed quite close to and directly behind, the organ pipe flame, which latter had about twice the height of the resonator flame. On sounding the pipe and holding the resonator quite near it, the two flames, by a slight adjustment, were made to appear as *one series of serrations* in the revolving mirror. Now on gradually moving the resonator away from the pipe, I saw another series of serrations (those of the resonator flame) slowly evolve themselves from the first series, and gradually slide over the latter, until, having removed the resonator from its first position by about 66 centimeters or a half wave-length (German), I had the pleasure of seeing the series of moving serrations standing exactly midway between the first or immovable series. On moving the resonator yet farther from the sounding pipe, I saw the serrations of the resonator flame continue their onward progress until the two series again coincided; and on measuring the distance of the resonator from its first position near the pipe, I found it to be equal to a whole

wave-length of the note UT_3. When I had removed the resonator one and a half wave-length, I again saw the serrations of the resonator flame bisecting the spaces between the serrations given by the organ pipe flame, and when the resonator had progressed from the pipe to a distance equal to two whole wave-lengths I saw that the serrations of its flame had progressed to another coincidence with those of the organ pipe; and so on, until I had determined on the line of the resonator's motion *all the phases of vibration* corresponding to three whole wave-lengths. I now moved the resonator until I had again caused the serrations of its flame neatly to bisect the spaces between the serrations of the organ pipe flame, and moving around the organ pipe, with the resonator held at such distances from it that the bisections were steadily kept, I described in space the wave surface of the sounding pipe. This surface I found approximately to be an ellipsoid with its foci at the top and bottom of the pipe. Nothing could be more satisfactory, and it was charming to behold how neatly the surface could be determined; for a small change in the distance of the resonator from the pipe produced a sensible shifting of the serrations. I now substituted for the resonator an organ pipe, in every respect similar to the one on the bellows, and with it I repeated the wave-length measures previously made with the resonator; indeed the column of air in the pipe in my hand responded so perfectly to the sounding pipe that I thought it gave more marked results than those produced with the resonator.

The manometric flame-micrometer.

In the experiments described above, we examined the appearances in the mirror with the unaided eye, and with it estimated when coincidences and bisections occurred; but to obtain results of precision, a method was devised which determines neatly these critical points. For that purpose I have invented the following micrometer, founded on a beautiful suggestion of Dr. R. Radau, who thus describes in his excellent "*l'Acoustique*" (Paris, 1867, p. 272), a method of observing the flames of two similar sounding organ pipes. "We attach to the two pipes two of König's flames arranged so that the point of one flame reaches above a small fixed mirror which hides its base, but which shows by reflection the base of the other flame. This produces the illusion of a single flame. If now we observe this hybrid image in the revolving mirror while we sound the two pipes, the point separates from the base, which proves that the two flames shine *alternately*, and the one retracts while the other elongates; if the two tubes act on the same flame, the effect is null, and the flame remains immovable." By placing the above "small fixed mirror" on a divided circle; or by

silvering its back and determining its angular displacements around a vertical axis by the method of Poggendorff,—that is, by observing through a telescope, the reflections of a fixed scale from the back of the mirror,—we have devised a simple and precise micrometer for ascertaining the amount of displacement of the resonator's flame. For, having once determined, for a given note, the amount of angular motion of the mirror required to move the bases of the flames over the distance between the centers of two contiguous serrations we have the angular value of a displacement equal to that caused by moving the resonator through a wave-length, and a fraction of the turn required to produce the above movement of the bases of the flames will be equal to that produced by the remove of the resonator over a corresponding fraction of a wave-length. Thus can be measured very small fractions of a wave-length. Indeed, even with the unaided eye and without the use of the micrometric mirror I have distinctly detected a displacement of the flames on moving the resonator, (UT_3) over only 3 centimeters or $\frac{1}{44}$th of a wave-length, and with the micrometer I feel assured that I can determine the wave-surface of a body giving the note UT_3 to one centimeter of its true position. Of course with higher notes we shall get a proportionally closer determination. But the object of this paper is not to present numerical results; I reserve these for a subsequent communication, in which I will also present diagrams of apparatus and the appearances of the flames in various experiments.

I will here remark that the success of the experiments depends on the resonator with its attached tube being in perfect unison with the organ pipe; also, the relative heights and positions of the flames should be so adjusted that the sharpest definitions are obtained in the rotating mirror, and thus be able to detect and measure the effects of small changes in the position of the resonator; but these and other manipulative details will readily occur to any physicist who repeats the experiments.

Applications of the Method.

When the method I have here blocked out shall have been reduced to the refinement which it is susceptible of, I feel confident that we will have in our hands the power to attack many problems of high theoretic interest which have heretofore been deemed beyond the reach of experiment. Its application to such are so numerous that they are almost co-extensive with the phenomena of sound.

The actual experimental determination of wave-surfaces in free air and in buildings can now certainly be accomplished; and such determinations may serve to extend our knowledge in the direction of giving the proper laws which should govern

architects in their construction of rooms for public assemblies.

The differences, if any, in the velocities of sound, corresponding to vibrations differing in intensities and frequencies, may be determined by the use of reflectors, and the direct observation on any changes in wave-lengths different from those which should be given on the assumption that notes of various intensities and heights are propagated with the same velocity.

We can determine a wave-length quite accurately by the following arrangement of apparatus. Take an organ pipe with a resonator in unison with it, and place the resonator in a fixed position opposite the mouth of the pipe, then lead tubes from the capsules of pipe and resonator to contiguous jets, and adjust their flames to coincidence or to bisection of serrations; using for this purpose the manometric micrometer. Now suppose, for simplicity, that the pipe gives 340 complete vibrations in a second; then, as the velocity of sound is 340 meters per second, it is evident that in $\frac{1}{340}$th of a second an aerial pulse will traverse one meter. Therefore, if all things else remain the same, and we lengthen the resonator tube $\frac{1}{2}$ meter, the serrated flames of the resonator will be displaced $\frac{1}{2}$ of the distance between the centers of two contiguous serrations; and if the tube be lengthened 1 meter, or *one wave-length*, the displacement will amount to the entire distance separating the centers of two contiguous serrations; and for n number of wave-lengths of elongation of tube, we shall have n number of such displacements. Thus can be measured a wave-length; and if the number of vibrations given by the pipe be accurately known, we can reach with the manometric micrometer an accurate determination of the velocity of sound.

Finally, we are bold enough to believe that we have in the highest development of the method, a means of tracking in the air the resultant wave-surface of combined notes; and, in short, of bringing the exploration of acoustic space to approach somewhat to that precision of measurement which, for over half a century, has characterized the study of the æthereal vibrations producing light.

September 21st, 1872.